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<b>(54) Title:</b> DIATOMITE-MODIFIED PAVEMENT		
<b>(57) Abstract</b>  A method of making and the resulting diatomite-modified pavement. The addition of small amounts (0.5 to 2%) diatomite by weight to conventional pavement mixes, serves to increase density, viscosity, aggregate interlock and temporarily volumetrically extends the asphalt improving compactability resulting in an emplaced pavement that has lower air and water permeability without increased instability. The improved strength of the mixed and abrasion resistance of the mastic enable the thickness of wearing course overlays to be reduced without detrimental effects of wear life. The addition of diatomite makes the pavement mix more forgiving of errors in asphalt and aggregate amounts and can result in significant reduction of cost/sq. yard of pavement.		

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## DIATOMITE-MODIFIED PAVEMENT

Background and Summary of the Invention

The present invention is related to hot mix asphalt pavement mixtures. More particularly, the present invention is directed to a diatomite modified hot mix asphalt pavement which has an amount of asphalt within the normal range, but which has improved aggregate interlock and superior compactability. This application is a continuation-in-part of United States patent application serial number 06/343,075 filed January 27, 1982.

In a pavement mixture the asphalt plus the fines (material passing 200 mesh) forms the mastic. The asphalt mastic, in conjunction with the fine aggregate (those passing No. 8 or No. 10 mesh), functions as what may be termed the mortar, holding the coarse aggregate together. The adhesive/cohesive strength of the mastic is inversely proportional to its thickness; that is, the thinner the coating of mastic on the aggregate, the stronger the bond and the more stable the pavement. However, thin film coatings oxidize more quickly so that the asphalt loses its pliability and becomes crumbly. The resistance to traffic loading is drastically decreased causing raveling and cracking. Similarly, thin coatings are more susceptible to water penetration. For these reasons, many pavement manufacturers increase asphalt content to try to extend pavement life. In fact, the foremost pavement design criteria requires the asphalt content to be as high as possible without permitting overcompaction of the pavement by traffic. High-asphalt containing mixes have thicker films, fewer voids, lower permeability and are, therefore, less subject to oxidation and water degradation. However, merely increasing asphalt content above normal will have an adverse affect on pavement stability in most pavements. The increase in thickness of the mastic coating on the aggregate particles leads to over compaction permitting bleeding, rutting and shoving. Further, asphalt is generally the most expensive pavement ingredient, so increasing its amount in the mix would be a costly remedy.



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There are principally two forces which serve to hold the pavement mix together: adhesive/cohesive strength and aggregate interlock (frictional forces between the aggregate particles which resist displacement). The cohesive strength of the pavement (i.e., the cohesive strength of the mastic) depends primarily on the grade of asphalt, which will influence such factors as the interfacial tension between asphalt and aggregate and the degree to which the asphalt can wet and adhere to the aggregate. (Note, the characteristics of the aggregate and fines also have some influence on these factors which affect cohesive strength). The other force, aggregate interlock, is a function of the size gradation of aggregate in the mix, the shape (angularity) and surface texture of the aggregate, and the density of aggregate packing. It should be noted that as used here, the term "aggregate interlock" includes those frictional forces of all particles in the mix regardless of size (i.e., including fines). When asphalt paving materials experience temperatures above 90°F, the asphalt begins to soften (i.e., to lose cohesive strength) and aggregate interlock plays the key role in maintaining pavement stability.

Mineral fillers are sometimes employed in an attempt to increase viscosity and density of pavements in hopes of increasing aggregate interlock and to volumetrically extend the asphalt in pavements with normal asphalt levels to increase compactability. Finely ground rock dusts, such as limestone dust, will volumetrically extend the asphalt. The volumetric extension does have the desired effect of decreasing void content of the pavement. However, rather than increasing aggregate interlock, the inclusion of such a filler can actually decrease aggregate interlock. This results from the fact that the volumetric extension of the asphalt is permanent which serves to increase the thickness of the mastic film. A thicker mastic film increases the separation between the aggregate particles and interferes with particle friction (i.e., aggregate interlock). Depending on the filler and its extender capabilities, the increased thickness of the mastic can actually outweigh any benefits from increasing density. Further, permanent volumetric extension of the asphalt leads to instability of the pavement (rutting and shoving of the pavement). Therefore, the use of such a rock filler in an attempt to increase density and compactability, to thereby extend useful pavement life by



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reducing voids and, hence, oxidation rate and water susceptibility, will generally prove ineffective and may well have an opposite effect.

Many fillers (rock dusts included) can increase viscosity as much as three fold making placement difficult or impossible. Even  
5 smaller increases in viscosity can prevent proper compaction with the result that the emplaced pavement has an excessive void content accelerating oxidation hardening and water permeability. In fact, care must be taken in determining the proper amount of diatomite to be added so as to avoid excessive viscosity increases. Similarly, if the filler  
10 is highly absorptive, its addition will not extend the asphalt and facilitate compaction. Rather, the filler will adsorb (absorb and hold) the asphalt making proper compaction impossible.

It has been discovered that diatomite when added in small amounts (1/2 to 2%) can function as a particularly suitable temporary  
15 asphalt extender in the hot mix. Its high surface area per unit weight and the open micro-structure of the diatoms inhibit asphalt flow preventing bleeding of the asphalt. This same open micro-structure in combination with the other constituents of the mix, prevents over-compaction by creating a lattice-like structure. This lattice  
20 structure serves to maintain proper dispersion of the fines within the mastic and prevent their settling out. Surprisingly, diatomite's high surface area and open micro-structure do not also unduly increase viscosity, which would make placement and compaction difficult. Even more surprisingly, the highly absorptive diatomite does not adsorb the  
25 asphalt immediately, which would rob the pavement of its high-asphalt content characteristics. Apparently, the pressure of the outgassed water vapor contained by the diatoms, and/or the extremely small tertiary openings (.03 microns) in the diatoms inhibit asphalt adsorption until after the pavement cools below 200°F i.e., until  
30 after the pavement is in place. Then the diatomite begins to adsorb the asphalt.

Further, diatomite's unique structure make it peculiarly adapted to reduce void content and increase density. The various shapes and sizes of diatoms and diatom fragments as well as the ability  
35 of the diatom fragments to break further, enable diatomite particles to fill almost all the gaps in a pavement aggregate. Therefore, diatomite modification of pavement provides a material which exhibits increased



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density and viscosity achieving the compactability and improved life of a high-asphalt content pavement as well as improved shear strength resulting from improved aggregate interlock, and better erosion resistance of the mastic, without any increase in bleeding, rutting or shoving, characteristic of high-asphalt content mixes and other extended asphalt mixes. In fact, with the adsorption which occurs after the pavement is emplaced, the chances of bleeding, rutting and shoving are significantly reduced. Diatomite's capacity to both extend and adsorb asphalt make it a unique additive which "forgives" errors in mix design. Further, the increase in shear strength of the mix and abrasion resistance of the mastic suggest that the thickness of the overlay may be decreased without reducing wear life, with a corresponding reduction in the cost of placement.

Other features, advantages and characteristics of the present invention will become apparent after a reading of the following description.

#### Brief Description of the Drawings

FIGS. 1A - 1E are photographs of core samples taken from five different pavement mixes after eleven months of wear in Houston and depict respectively:

FIG. 1A are samples of a standard (5.5% asphalt) pavement containing no diatomite;

FIG. 1B are samples of Mix II containing 7.4% asphalt and 1.8% diatomite;

FIG. 1C are samples of Mix I containing 6.6% asphalt and 0.6% diatomite;

FIG. 1D are samples of Mix III containing 7.3% asphalt and 2.4% diatomite;

FIG. 1E are samples of Mix IV containing 6.0% asphalt (normal concentration) and 0.6% diatomite;

FIGS. 2A - 2D are photos of core samples taken from four different pavement mixes placed in Calgary, Alberta, said photos depicting respectively:

FIG. 2A is a sample from a pavement mix containing 7.3% asphalt and 2% asbestos fiber;

FIG. 2B is a sample from a pavement mix containing 7.8% asphalt and 2% diatomite;



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FIG. 2C is a sample from a pavement mix containing 6.5% asphalt and 1% asbestos fiber;

FIG. 2D is a sample from a pavement mix containing 6.5% asphalt and 1% diatomite;

5        FIG. 3 is plots and projections for two pavements including a standard pavement containing 6% asphalt (curve 'A'), and an asbestos modified pavement containing 7.5% asphalt and 2% asbestos fiber (curve 'B'), from pavement mixes used in constructing the Trans-Canada highway. Superimposed on these curves for comparison are four data  
10 points from samples taken from four pavement mixes placed in June ("C" Mix) and October ("B" Mix) of 1981 in Alberta, Canada with cores taken in October, 1982. The respective mixes for these data points are set forth in the "Key"; and

FIG. 4 is a graph indicating how stabilometer readings vary  
15 with asphalt content for conventional pavement mixes and showing the benefits of adding small amounts of diatomite to the standard Houston plant mix shown in FIG. 1A.

Detailed Description of the Preferred Embodiments

As described more fully in the aforementioned copending U.S.  
20 Patent Application Serial No. 06/343,075 filed January 27, 1982 three different sample mixtures of diatomite-modified pavements were prepared using a natural (or uncalcined) grade of diatomite sold by MANVILLE CORPORATION under the trademark "CELITE 292" and various increased asphalt contents. These sample mixtures of dense graded pavement were  
25 emplaced on a heavily trafficked street in downtown Houston along with a conventional mix which contained no diatomite. While the principle purpose of these experimental emplacements was to determine if diatomite, in suitable amounts, could stabilize high-asphalt containing mixes, a fourth mix was also put down. That mix contained no increase  
30 in asphalt (i.e., a standard 6% by weight) and 0.6% diatomite. After eleven months of downtown auto and truck traffic and Houston weather (intense heat and heavy rainfall which both have potentially adverse effects on pavement), three core samples were taken from the tire paths of each of the five mixes. These core samples appear in FIGS. 1A-1E.

35        FIGS. 1A - 1D pertain to the use of large amounts of diatomite to stabilize increased asphalt contents. These figures are presented here as a means of comparison to FIG. 1E which shows the core





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sample of Mix IV containing a normal amount of asphalt (6%) and 0.5% diatomite. It was this experimental placement originally intended as a second control (along with the standard mix) for Mixes I, II and III, that led to the discovery of the benefits of small amounts of diatomite as a filler/extender.

As a result of this initial experimental placement and subsequent plant and laboratory samplings, it has been determined that additions of small amounts (0.5 to 2% by weight) of diatomite to pavement mixes containing normal levels (5 to 12% by weight, depending on the mix) of asphalt serve to temporarily extend the asphalt increasing the density and viscosity of the mix and enabling improved compactability during placement, such that the void content of the pavement may be reduced thereby decreasing the susceptibility of the pavement to oxidation hardening and water degradation. This extender capability is possible inspite of diatomite's natural tendency to adsorb (absorb and hold) the asphalt. Apparently, the moisture within the diatoms (typically from 3 to 6% by weight), is vaporized upon addition of the diatomite to the asphalt-coated aggregate hot mix (generally heated to about 350°F). This water vapor is outgassed slowly over a period of hours by the diatoms (due to Van der Waals' forces) until the mix cools below 200°F (i.e., until after initial compaction) and this outgassing delays adsorption of the asphalt. Obviously, the length of time during which absorption is delayed could be varied by increasing or reducing moisture level of the diatomite. In addition to its extender capabilities, diatomite improves the aggregate interlock of the pavement which is reflected in increased strength in shear tests.

While it is intended that diatomite be added to asphalt mixes having normal amounts of asphalt to function as an extender (i.e., in lieu of adding additional asphalt), it will be appreciated that what may be considered a "normal" amount of asphalt by some paving authorities may in fact be an inadequate amount to properly coat the aggregate. It is therefore within the scope of this invention to use diatomite with mixes in which the asphalt is increased on the order of 1/2 to 1% to counterbalance such a deficiency. It will also occur to the artisan that because diatomite temporarily extends the asphalt, it may actually be possible to reduce the amount of asphalt below "normal"



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levels. While this is indeed a possibility, it is strongly recommended that the diatomite used in such mixes be pretreated with a silicone surfactant or petroleum material or other suitable treatment, which is designed to make the diatomite hydrophobic. This will eliminate the risk of making the mix subject to water degradation as a result of the reduced asphalt content (i.e., unexhausted absorptive capacity of the diatomite).

Comparison of FIGS. 1B - 1E with the standard asphalt mix of FIG. 1A demonstrates the effectiveness of diatomite in improving the abrasion resistance of the asphalt mortar. The core samples of FIG. 1A show a typical mortar abrasion rate on the order of 1/4" per year. Additional abrasion of the mortar in the standard mix will enable the surface aggregate to begin raveling. All four of the diatomite mixes, on the otherhand, show mortar with superior abrasion resistance. In addition, the mortar is effectively a wear resistant surface which shares the load with the aggregate. The wear benefits of diatomite-modified pavements are, then, twofold: 1) the abrasion-resistant mortar stays in place holding the aggregate firmly against raveling; and, 2) the mortar is capable of resisting wear which distributes the wear load more evenly over the pavement surface slowing pavement erosion. These results suggest that a thinner than normal overlay of diatomite-modified pavement may be used without detrimental effects on wear life. It should be noted, however, thinning of the overlay will accentuate the need for a sound foundation (i.e., care must be taken in repairing existing roadway if the overlay is placed directly over old asphalt).



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TABLE I shows the core analysis for the five samples shown in FIG. 1.

TABLE I

5		Std. Mix	<u>Diatomite Modified Mixes</u>				
		Control	I	II	III	IV	
	Diatomite content, % wt.	—	0.6	1.8	2.4	0.6	
	Asphalt content, % wt.	5.5	6.7	7.4	7.3	6.0	
10	Density gm/cc	2.28	2.31	2.28	2.35	2.33	
	Void content, % Vol. (vac.sat.)	4.2	1.3	2.0	2.8	1.7	
	<u>Recovered Asphalt *</u>						
	% wt. (original penetration 104)	4.8	6.7	7.1	6.9	5.8	
	Penetration **						
15	(0.1mm/5 sec at 77°F)	42	89	94	73	82	
	Gradation (all samples 200m 100m 50m 30m 16m 8m 4m 3/8in 1/2in sieve mesh size unless otherwise stated)						
	% passing	8 12 17 22	29	41	61	93 100	

\*These tests performed by Chicago Testing Laboratory

\*\*ASTM D-5 test in which a 100 gram weight is placed on a needle and penetration of the sample measured after 5 seconds at 77°F in tenths of a millimeter.



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As TABLE I shows, Mix IV, like the other diatomite-modified pavement mixes, exhibits two benefits of diatomite addition: 1) a significant reduction in void content and, 2) a reduced rate of asphalt hardening. These benefits are interrelated with the first contributing significantly to the second. The reduction in the percent voids reduces the internal surface area exposed to oxidation hardening and to water degradation. In fact, the diatomite modified samples were virtually impermeable to water (in test run using a 12" hydraulic head). These factors obviously contributed to the reduced levels of asphalt hardening reflected by the penetration data shown in TABLE I.

FIGS. 2A - 2D are photographs of cores taken from experimental pavements emplaced in Calgary, Alberta, Canada. The purpose of these emplacements was to compare the diatomite-modified pavements to asbestos fiber reinforced pavements which have been extensively used in Canada for the past 20 years.

FIG. 2A is a core sample of a pavement mix containing 7.8% asphalt and 2% asbestos fiber; the same mix replacing the fiber with 2% diatomite is shown in FIG. 2B. FIG. 2C is a core sample of a pavement mix containing 6.5% asphalt and 1% asbestos fiber; FIG. 2D is the same mix replacing the fiber with 1% diatomite. Visual inspection of the cores shows the mastic of the diatomite-modified samples to have superior abrasion resistance to the mastic of the asbestos fiber cores. TABLE II shows the core analysis for the four samples shown in FIG. 2.

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TABLE II

<u>"B Mix"</u>						<u>"C Mix"</u>					
Asbestos			Diatomite			Asbestos			Diatomite		
5	Additive										
	Content (%wt.)	1		1		2		2			
	Asphalt % wt.										
	(orig. pen. 162)	6.5		6.5		7.8		7.8			
	Density (gm/cc)	2.424		2.427		2.354		2.368			
10	Void Content, %										
	Vol. (vac.sat.)	4.4		4.3		2.8		3.1			
	Air Permeability										
	(ml/min)										
	(1" H <sub>2</sub> O press.)	52		7		18		0.9			
15	<u>Gradation (% passing)</u>										
	200m	100m	50m	30m	16m	8m	4m	3/8in	1/2in	3/4in	
	"B Mix"	6	9	16	27	38	46	58	81	92	100
	"C Mix"	4	6	15	23	36	46	61	91	100	---

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TABLE II data indicate that, although both the asbestos and diatomite samples have generally equivalently high density and low percent voids, the diatomite cores are substantially less permeable to air (and therefore less subject to oxidation). Similarly, the diatomite samples should be less permeable to water since there is some tendency of the asbestos fibers to cause a wicking action which is not present in diatomite because of the more varied non-linear structure of the diatoms.

TABLE II data suggest that the diatomite samples should oxidize (age harden) more slowly than their asbestos counterparts. In order to substantiate this, asphalt penetration tests were performed on core samples taken some twelve to sixteen months after original placement. The results of these tests are shown in FIG. 3 and have been plotted with two life expectancy curves A and B for pavements used in the construction of the Trans-Canada highway in 1967. Curve A represents a life expectancy plot for a pavement containing 7.5% asphalt and 2% asbestos fiber. The points on each curve represent actual asphalt penetration measurements made from cores taken immediately after placement, at age 2 years and at 6 years. The dotted line at a reading of 30 indicates the generally accepted critical minimum value below which the pavement loses sufficient pliancy and the pavement begins to crack and ravel.

As can be seen in FIG. 3, the two diatomite samples do, indeed, out perform their asbestos counterparts and can be expected to last as long or longer than the asbestos-modified pavement of curve B. This would give those diatomite pavements life expectancies from 37 to 45 years. While factors such as weather and heavy road traffic may make it difficult to realize such a longevity, it can be expected that the diatomite-modified pavement will last up to 60% longer than standard asphalt mixes.

At the time the Calgary experimental samples of the "C" Mix were placed, small amounts of both the asbestos-modified and diatomite-modified mixes were taken from the paver. These samples were compacted in the laboratory using gyratory shear and subjected to a variety of tests for comparative purposes. The results of these tests are shown in TABLE III.



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TABLE III

	<u>Asbestos</u>	<u>Diatomite</u>
Additive Content		
5 (% wt.)	2	2
Asphalt Content		
(% wt.)	7.8	7.8
Density (gm/cc)	2.24	2.26
Void Content, % Vol.		
10 (vac.sat.)	0.7	0.3
<u>Plate Flexure*</u>		
Load at Crack, lbs	94	98
Deflection at Crack, in. *	0.12	0.10
15 Ultimate Load, lbs	99	117
Deflection at ult., in.	0.20	0.22
*Sample at 140°F		

20 The test results set forth in TABLE III show the diatomite samples out performing the asbestos samples in almost every test category. These data, then, support the visual abrasion resistance and asphalt penetration test results in confirming that diatomite-modified pavement mixes can be expected to last as long or longer than asbestos-modified mixes.

25 Attempting to confirm diatomite's performance with various grades of asphalt and aggregate types and gradations, additional tests were run using two different samples taken from a Los Angeles paver. The two mixes had maximum stone sizes of 3/8" and 1/2" respectively and each used a very hard grade of asphalt. These samples were returned to  
30 the laboratory, subdivided, and various amounts of diatomite and additional asphalt added to produce the desired test mixes. These mixes were then compacted using Marshall compaction prior to administering the various analytical tests. The results of these tests appear in TABLE IV.

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TABLE IV

<u>First Sample</u>									
	Asphalt % wt.	5.2	5.2	5.7	5.7	6.2	6.2	6.2	6.7
5	(orig. pen. 42 ± )								
	Diatomite Content								
	(% wt.)	0	0.5	0	0.5	0	0.5	1.0	1.0
	Density*	2.325	2.345	2.33	2.36	2.335	2.39	2.36	2.375
	Shear Strength								
10	(140°F, psi)*	26.2	49.8	27.6	54.5	39	41	39	45
	Gradation (all 1st								
	sample mixes)	20u	100m	50m	30m	16m	8m	4m	3/8in. 1/2in.
	% passing	8	12	17	22	29	41	61	91 100
<u>Second Sample</u>									
15	Asphalt Content								
	(% wt.)	5.7	6.2	6.2	6.7	6.7	7.0		
	Diatomite Content								
	(% wt.)	0.5	0.5	1.0	0.5	1.0	1.0		
	Density*	2.308	2.327	2.361	2.338	2.37	2.384		
20	Shear Strength								
	(140°F, psi)*	28	39	48	34	53	52		
	Gradation (all 2nd								
	sample mixes)	200m	100m	50m	30m	10m	4m	3/8in	1/2in
	% passing	1	3	10	23	39	80.5	100	---
25	*Values given are averages of two measured values.								



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Test results from the first sample indicate a significant increase in shear strength from the addition of 0.5% diatomite to the 5.2 and 5.7% asphalt mixes. In fact, for the first sample, 0.5% diatomite appears to be better than 1.0%. On the otherhand, for the  
5 second sample 1% diatomite has an appreciably greater effect on shear strength than 0.5%. This seeming inconsistency is believed to be a result of differences in aggregate interlock. (Note, since the shear tests were performed on samples at 140°F, i.e., above the softening temperature of asphalt, the shear strength measurements are principally  
10 reflective of the degree of aggregate interlock.)

As has been previously noted aggregate interlock is affected by such factors as the size gradation of the aggregate, the shape (or angularity) and surface texture (degree of abrasiveness) of the aggregate and the density of aggregate packing. Aggregate interlock,  
15 or the frictional resistance to displacement, is a result of the synergistic interaction of all the aggregate particles. If there are too few fines within a mix, then the interstices between the larger stones are not filled, resulting in low aggregate packing and a lower degree of aggregate interlock within the aggregate.

20 Diatomite can contribute to aggregate interlock due to its angularity and ability to increase the density of aggregate packing. In fact, diatomite is peculiarly capable of increasing aggregate packing because of its diversity of particle sizes and shapes and the ability of the diatom fragments to fracture and "fill in" the spaces  
25 between aggregate particles. These fractured fragments can tailor themselves to fit the size and shape of the opening. The diatomite forms a lattice-like structure with the other fines in the mastic and prevent their settling out. On the otherhand, if the aggregate gradation of the mix is deficient regarding small fines, additional  
30 amounts of diatomite will be necessary to fill the resulting voids. The second sample of TABLE IV had a deficiency of fines that 0.5% diatomite could not completely fill. For this reason, the 1.0% mix had better density and shear strength values, with the additional diatomite substituting for the missing fines. In the case of the first sample,  
35 0.5% diatomite adequately fills the voids. The additional diatomite added with the addition of 1% diatomite has no particular positive or negative effect in the 6.2% asphalt mix of the first sample but appears



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beneficial in the 6.7% asphalt mix, overcoming the adverse effects of added asphalt.

To substantiate these results, stabilometer tests were run on several samples of the Houston plant mix modified with 0.5% diatomite. (The Hveem stabilometer test, named for its inventor, is considered the best method to determine the degree of aggregate interlock and is relied on heavily throughout the western United States.) The results of these tests are shown with a standard asphalt mix curve in FIG. 4. As can be seen from the standard curve, the addition of asphalt reduces the particulate friction (stabilometer value), which is a result of increased thickness of asphalt coating on the aggregate particles. The addition of 0.5% diatomite to mixes containing 6, 6 1/2 and 7% asphalt resulted in higher stabilometer values than for the standard mix. This benefit is particularly significant with the 6 1/2 and 7% mixes where the addition of diatomite prevented the stabilometer value from slipping below the accepted critical minimum value of 40. It is apparent that the increase in aggregate interlock afforded by diatomite and diatomite's adsorptive capabilities counter the adverse effects of adding asphalt.

As noted previously, diatomite temporarily volumetrically extends the asphalt. The following calculations show the relative merits of adding diatomite as an extender as opposed to a rock filler such as limestone, for example. The limestone filler has a specific gravity of 2.5 g/cc or 156 lb/ft<sup>3</sup>. If it were desired to add 6% filler to one ton of 6% asphalt mix, 120 pounds of limestone dust would be added. A typical specific gravity for asphalt is 1.04 g/cc or 65 lb/ft<sup>3</sup>. The 6% (120 lb.) of asphalt would occupy  $120/65=1.85$  ft.<sup>3</sup>. The 120 lb of limestone filler will occupy  $120/156=.77$  ft.<sup>3</sup>. The addition of 6% limestone dust to the one ton of asphalt mix will extend the asphalt volumetrically by  $.77/1.85 \times 100=41.6\%$ .

Diatomite (specifically the aforementioned "CELITE 292") has a wet density of 16.1 lb/ft.<sup>3</sup> and an apparent solid density of 1.8 g/cc=112.3 lb/ft.<sup>3</sup>. The same .77 ft.<sup>3</sup> (or 41.6%) asphalt extension can be performed by  $.77 (16.1)=12.4$  lb or 0.62% diatomite. The truly significant difference between the addition of diatomite and limestone dust as a filler does not lie in the almost ten fold difference in weight (12.4 lb vs. 120 lb.) necessary to achieve the same volumetric



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extension. The most important difference lies in the net end effect on the stability of the mixer.

As noted above, diatomite has a wet density of 16.1 lb/ft.<sup>3</sup> and an apparent solid density of 112.3 lb/ft.<sup>3</sup>. Calculating both the volume occupied by 16.1 lbs of solid ( $V_1$ ) and of wet ( $V_2$ ) diatomite gives

$$V_1 = 16.1/112.3 = 0.143 \text{ ft.}^3$$

and

$$V_2 = 16.1/16.1 = 1.0 \text{ ft.}^3$$

The percent of volume of a cubic foot of diatomite available for absorption equals

$$(V_2 - V_1)/V_2 \times 100 = \frac{1.0 - 0.143}{1} \times 100 = 85.7\%$$

In actual practice not all of the capacity available for absorption is fully utilized. This may be a result of retained water vapor or may result because the tertiary openings within the diatoms are too small to be penetrated by the asphalt. In any event, 95% of the absorptive capacity seems to be the maximum asphalt absorption achievable. That is,  $85.7 \times .95$  or 81.4% of the volume of a diatomite sample is open space which can be occupied by asphalt. In fact, diatomite will adsorb .814 : (16.1/65) or 3.29 times its own weight of asphalt.

Accordingly, once the outgassing of the water vapor contained in the diatomite subsides (i.e., once the mix cools below 200°F), only 100-81.4 or 18.6% of the .77 ft.<sup>3</sup> of volumetric extension will remain. That means the actual final volumetric extension of the asphalt by the diatomite will amount to just  $.186 \times .77/1.85 \times 100 = 7.7\%$ . Since limestone dust has little if any absorptive capacity, the 41.6% volumetric extension originally created will remain. The limestone-extended mastic coating on the aggregate particles will be correspondingly thicker and have less adhesive/cohesive strength. Further, the thicker mastic will interfere with interparticle friction reducing aggregate interlock.

The 41.6% permanent volumetric extension of the asphalt obtained with limestone can be expected to have an effect on stability similar to the addition of  $.416 \times 6 = 2.5\%$  asphalt. As can be seen from FIG. 4, the addition of the equivalent to 2.5% asphalt to even a 5% asphalt mix would have a drastic effect on stabilometer reading



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(possibly dropping the the reading 25 points or more, causing bleeding, rutting and shoving). On the otherhand, .62% diatomite could at worst be the equivalent of adding .077 x 6 = .5% asphalt causing no more than a 4 point drop in the stabilometer reading. However, we have seen that the addition of 0.5% diatomite actually offsets the ill effects of such a small permanent volumetric extension by increasing aggregate interlock. Accordingly, the addition of small amounts of diatomite are expected to have no adverse effects on stability.

In the past, pavement contractors in the U.S. have opted for the use of harder asphalts as a means of preventing instability and of increasing adhesive/cohesive strength. These asphalts have a lower initial penetration reading with a correspondingly lower useful life (i.e., a shorter time to reach the critical minimum asphalt penetration). Experience with diatomite-modified pavements in Calgary, where softer asphalts are used, indicate that the use of diatomite with the softer asphalts can provide a stable pavement with greatly increased wear life. Diatomite optimizes the adhesive/cohesive forces in a mix and stabilizes the thinner asphalt by the combination of improved aggregate interlock and asphalt adsorption.

Normal pavement overlays have a thickness of between 1 1/2 and 2 inches. As previously noted, the wear resistance afforded to the mastic by diatomite and the improved shear strength it imparts, enables the thickness of the overlay to be reduced. It is recommended that the overlay thickness be on the order of two to three times the diameter of the maximum stone size of the aggregate. For an asphalt concrete having a maximum stone size of three-eighths inch, the overlay thickness should range from three-quarters to one and one eighth inches; for 1/2 inch stone from 1 to 1 1/2 inches. For stone filled sheet asphalt having a maximum stone size of one-fourth inch, the overlay thickness should range from about 1/2 to 3/4 inch. This thickness reduction can translate into significant reductions in the amount of material used and in the cost of per square yard placement.

It has been shown that the addition of small amounts of diatomite (0.5 to 2.0%) can function as a temporary volumetric extender of the asphalt in pavement mixes. The precise amount to be added to a particular mix to optimize the characteristics of the pavement will depend on such factors as size gradation of the aggregate and the grade



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of asphalt to be used. It will be appreciated, however, that the addition of diatomite will make a mix more forgiving. For example, the inclusion of diatomite can "forgive" the addition of too little asphalt by extending it or too much by adsorbing it. Diatomite can also

5 "forgive" the inclusion of too little fine aggregate, as previously discussed. The use of diatomite as a filler/extender expands an otherwise narrow range of percentages for the various ingredients in the mix. It is important that the diatomite be added to the mix after the aggregate has been coated with asphalt, as in the previous

10 application, so that the fragile diatoms will not be abraded by the aggregate. Preferably, the various aggregate components will be mixed in a pug mill or the like, to form a dry mix. Then, the mix will be raised to a temperature above 300°F; the asphalt added to and mixed with the dry mix to coat the aggregate. Finally, the diatomite will be

15 added to the mix and blended briefly (preferably not more than 30 seconds). The pavement should be laid and compacted before the temperature falls below 200°F so the diatomite will not adsorb significant amounts of asphalt before initial compacting has been completed.

20 Various changes, modifications and alternatives will become apparent following a reading of the foregoing specification. For example, should diatomite be used in a mix employing recycled pavement, the diatomite could function as a carrier for an asphalt rejuvenator which is typically employed in such mixes. Secondly, the moisture

25 content of the diatomite could obviously be changed to vary the length of time during which outgassing occurs as has been suggested. Further, although only one grade of diatomite has been used in these tests, its use is considered exemplary with the use of other grades producing similar results. Lastly, although the benefits of diatomite make it

30 particularly suitable for thin overlays, it is not intended that the use of diatomite be restricted thereto. Diatomite can be of some benefit to all hot mix asphalt pavements including standard overlays, binder courses, etc. Accordingly, it is intended that all such changes, modifications and alternatives as fall within the scope of the

35 appended claims be considered part of the present invention.



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## I CLAIM:

1. A process for increasing the aggregate interlock and compactability of a conventional hot mix asphalt paving material containing between 5 and 12 percent by weight asphalt without the need  
5 for appreciably increasing the percentage of asphalt in the mix, the process comprising blending from about 0.5 to about 2.0 percent by weight diatomite into said conventional asphalt paving material, said diatomite increasing the density and viscosity of the asphalt mix and temporarily volumetrically extending the asphalt in said mix, such that  
10 the paving material exhibits increased compactability until the temperature of the pavement material drops below 200°F without increasing the probability of surface bleeding, said diatomite adsorbing a substantial amount of asphalt after the paving material cools below 200°F.
- 15 2. A hot mix asphalt pavement mix comprising from between five and twelve percent by weight asphalt, from about 0.5 to 2.0 percent by weight diatomite, said diatomite increasing the density, viscosity and aggregate interlock of the pavement mix, the balance of said mix being aggregate and fillers having various gradations, said  
20 diatomite serving to temporarily volumetrically extend the asphalt such that said mix has improved compactability until its temperature drops below 200°F, said diatomite adsorbing a substantial amount of asphalt after the pavement cools below 200°F.
3. The asphalt pavement mix of Claim 2 comprising an asphalt  
25 concrete with a maximum stone size of three-eighths inch.
4. The asphalt pavement mix of Claim 2 comprising an asphalt concrete with a maximum stone size of one-half inch.
5. The asphalt pavement mix of Claim 2 comprising a stone filled sheet asphalt with a maximum stone size of one-quarter inch.
- 30 6. The asphalt pavement mix of Claim 2 formed as a wearing course overlay with a thickness in the range from about two to about three times the maximum dimension of said aggregate in the mix.
7. A process for manufacturing a pavement comprising mixing several aggregate and filler components having various gradations to  
35 form a dry mix, heating said dry mix to above 300°F, adding to and mixing with said dry mix from between 5 to 12 percent asphalt by weight



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to coat said dry mix, adding to and mixing with said asphalt-coated mix from about 0.5 percent to about 2.0 percent diatomite by weight to increase density, viscosity and aggregate interlock of the mix, said diatomite further serving to temporarily volumetrically extend the

5 asphalt, laying the resultant paving material, compacting and rolling said paving material before it cools below 200°F such that the emplaced pavement has decreased voids resulting in slower oxidation hardening and less water degradation.



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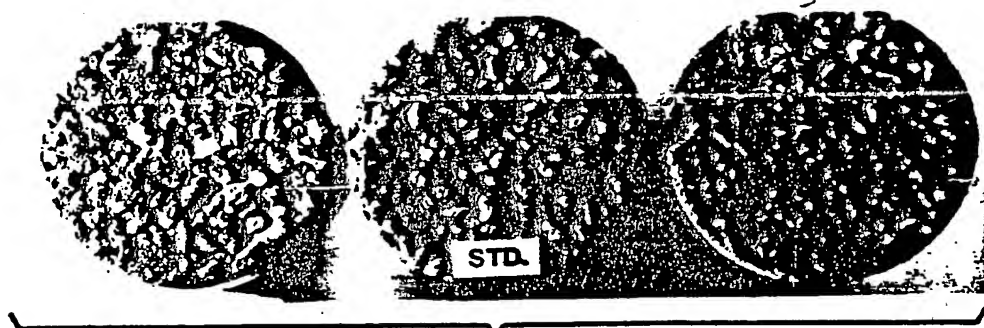


FIG. 1A

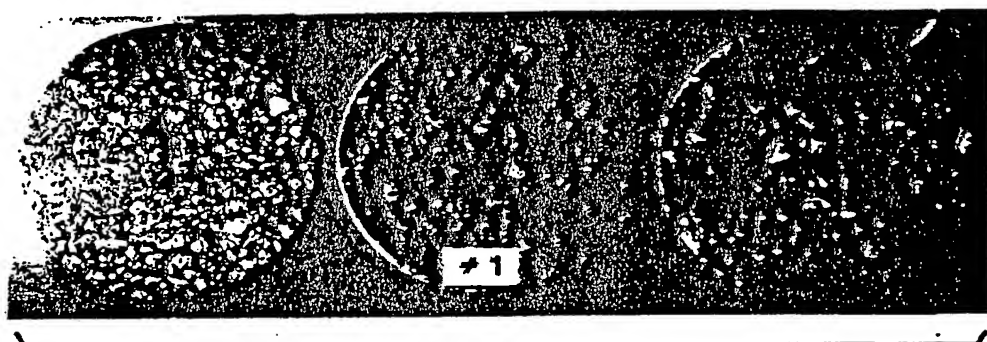


FIG. 1B

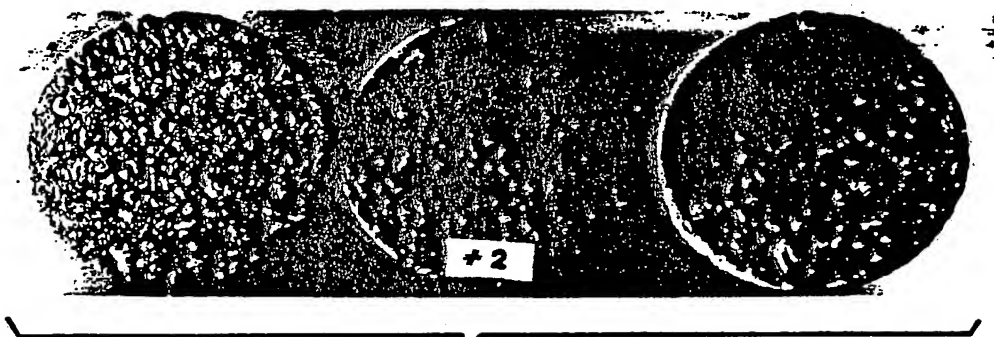


FIG. 1C

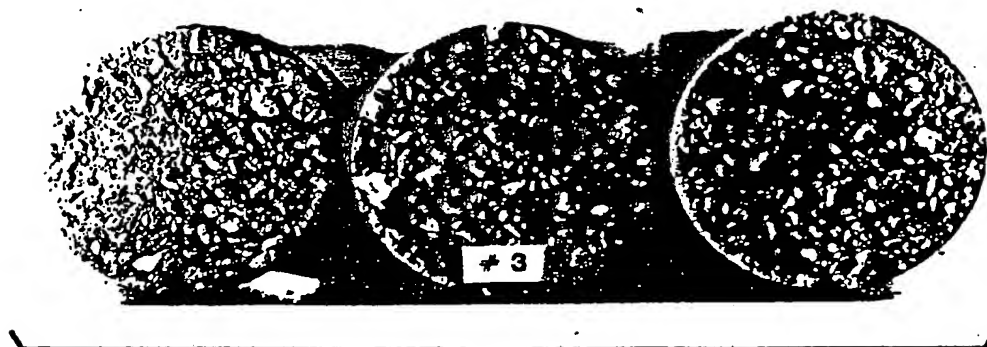


FIG. 1D

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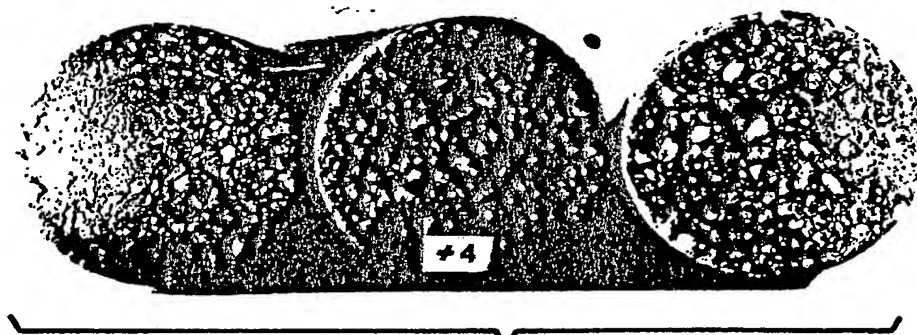
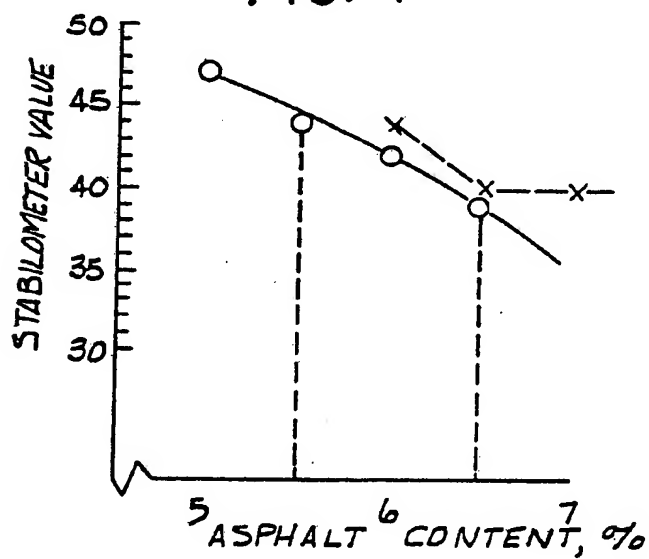


FIG. 1E

FIG. 4



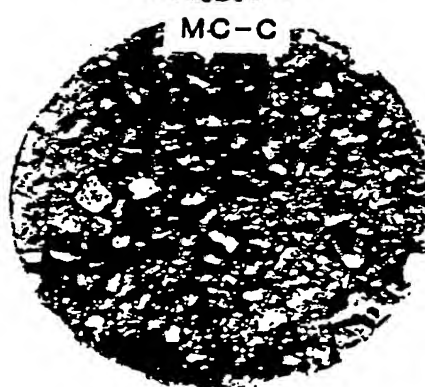
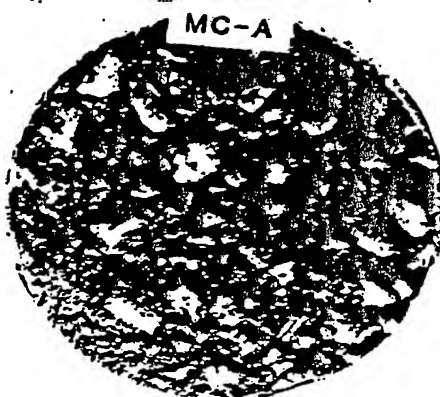
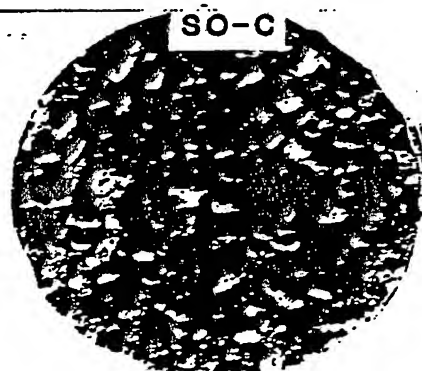
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*Fig. 2A*

*Fig. 2B*



*Fig. 2C*

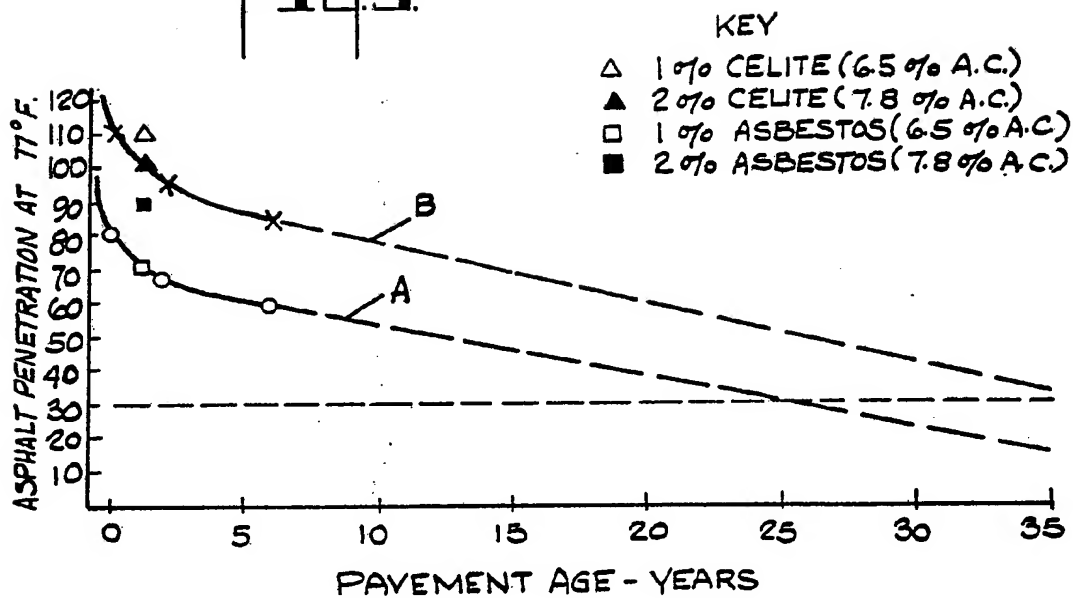
*Fig. 2D*

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Fig. 3.



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# INTERNATIONAL SEARCH REPORT

International Application No PCT/US 84/00040

<b>I. CLASSIFICATION OF SUBJECT MATTER</b> (If several classification symbols apply, indicate all) *		
According to International Patent Classification (IPC) or to both National Classification and IPC		
IPC <sup>3</sup> : C 08 L 95/00; E 01 C 7/22; E 01 C 7/26		
<b>II. FIELDS SEARCHED</b>		
Minimum Documentation Searched *		
Classification System	Classification Symbols	
IPC <sup>3</sup>	E 01 C; C 08 L	
Documentation Searched other than Minimum Documentation to the extent that such Documents are included in the Fields Searched *		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT</b> <sup>14</sup>		
Category *	Citation of Document, <sup>15</sup> with indication, where appropriate, of the relevant passages <sup>17</sup>	Relevant to Claim No. <sup>18</sup>
A	US, A, 2400563 (MARK) 21 May 1946 see the whole document --	1
A	US, A, 2877127 (MUNDING) 10 March 1959 see the whole document --	1
A	GB, A, 955049 (GULF STATES ASPHALT CO.) 8 April 1964 see the whole document --	1
A	US, A, 1987151 (MASON) 8 January 1935 see page 1, right-hand column, line 10 - page 2, right-hand column, line 7; page 3, table 1 --	1
P,A	WO, A, 8302619 (MANVILLE SERV. CORP.) 4 August 1983 see the whole document (cited in the application) -----	1
<p>* Special categories of cited documents: <sup>14</sup></p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&amp;" document member of the same patent family</p>		
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search <sup>1</sup>		Date of Mailing of this International Search Report <sup>2</sup>
11th April 1984		17 MAI 1984
International Searching Authority <sup>3</sup>		Signature of Authorized Officer <sup>10</sup>
EUROPEAN PATENT OFFICE		G.L.M. Kruydenberg

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON

INTERNATIONAL APPLICATION NO.

PCT/US 84/00040 (SA 6494)

This Annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 03/05/84

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 2400563		None	
US-A- 2877127		None	
GB-A- 955049		None	
US-A- 1987151		None	
WO-A- 8302619	04/08/83	EP-A- 0099400	01/02/84

For more details about this annex :  
see Official Journal of the European Patent Office, No. 12/82